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Research Article

Finned wafer baking plates for heat transfer and distribution

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ABSTRACT

Wafer baking is a recognized process in food industry, and there is a large worldwide demand to develop wafer baking equipment for the current trends, namely, high-productivity, high quality with lower wastes and lower energy expenditure. This work deals with the thermal design of the heating side of flat wafer baking plates in gas ovens seeking less heat, less baking time and better quality control. The key feature under study is the thermal interaction between the gas flames and the baking plates. Heat flows mostly by thermal radiation to the back of the baking plates which design is under study. Heat then reaches the opposite side where the batter (dough) is duly baked. The flames are modelled as a radiant solid surface with fixed geometry and uniform equivalent mean temperature. Steady, 2-d, heat conduction within the baking plate determines the superficial temperature field of the baking side. All the physics is modelled mathematically and solved in a commercial finite-element software. The method of Constructal Design is employed in order to explore possible designs of the back surface of the baking plates with the goal of providing uniform temperature heating at the baking side. We explored, for instance, the possibility of extended surfaces for a given volume of material. Variable rectangular, trapezoidal and parabolic straight long fins were considered. They varied in number and geometry. Results showed the baking plate with 17 fins provides a better heat distribution and increase of near 20°C from the plate with 3 fins. This means an overall gain of approximately 10%. In sum the new designs provide better heat transfer that in turn decreases the baking time, and it also improves heat distribution that in turn warrants product quality. Furthermore, the new designs provide the same mechanical resistance with less 17% material.

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1. INTRODUCTION

Biscuits, otherwise called as wafers, are known in Europe for centuries. They were initially baked between two cast iron plates (Moor, 1994). Production began in simple artisanal baking plates then evolved to large and complex automated ovens. Today, the main goals for improvements in wafer baking ovens are the process itself, the quality, productivity, automation, and ultimately reduction of wastes and energy (Mukherjee et al., 2018). In view of the large-scale production, even incremental gains lead to substantial benefits year-round, for instance Mukherjee

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et al. investigated the efficiency of oven and heat losses in the chimney stack and possibilities for waste heat recovery. The starting point to achieve those goals is the thermal interaction between the batter and the heat source. Batter is the raw dough, usually composed by starch, flour, sugar, other minor substances, and water which will turn into steam. Heat is provided by arrays of gas burners to the baking plate which in turn bakes the dough. Today's ovens work with a set of lower and upper baking plates that are mounted on a baking trolley (Fig. 1). The baking trolley moves through the oven in a loop over rails (Haas, et al. 1984). Heat is transferred to the baking trolleys through the tubular burners located under the cart at approximately 50 mm below. The burners are located along the longitudinal direction of the oven. The baking trolley moves horizontally along the oven. The plate fins are laid in the transversal direction to the burners.

The flames are modelled as space region with a fixed geometry high temperature slender fixed rectangle radiating heat. Heat flows mostly by thermal radiation to the back of the baking plates, which design is under study. Steady, 2-d, heat conduction within the baking plate determines the superficial temperature distribution of the opposite side where baking takes place. All the physics is modelled mathematically and solved in a commercial finite-element software (COMSOL, 2019).

The method of Constructal Design (Bejan and Lorente, 2008) is employed in order to study designs of the back surface of the baking plates. According to the method, the better designs promote greater access of the heat flow across the system (baking plate). For instance, we study the possibility of extended surfaces for a given volume of material. A variable number of triangular, rectangular, trapezoidal and parabolic fins were considered. It was tested from three to seventeen fins in a total of sixty-eight computer simulations. The study of fins configuration was inspired in Bejan and Almogbel, 2000 that dealt with purely convective fins for different end application.

The thermal impact of different designs is reflected in the overall temperature level and its distribution on the baking surface: the greater the access, the higher the temperature, and the lower the nonuniformity. It is fair to acknowledge that convective fin designs have been addressed widely in the literature, in particular Bejan and Almogbel, 1999, Torabi, et al., 2013, Lane and Heggs, 2005 and in heat transfer literature (Bejan, 2022). Our group has also approached the issue in a conference paper (Carzino et al., 2019).

In sum, this paper deals with the influence of the shape and the number of the fins on the heat flow through the baking plates, novel fin shapes, homogeneous baking temperature and possible weight reduction of the baking plate is the object of this study. The target is therefore to provide better access to the heat from the burners viewing on side of the baking plate to the opposite surface where the baking takes place. Results showed that indeed the design of heating side of the plates can provide significant improvement for instance, near 10% between two distinct designs.

The new designs augment heat transfer, that in turn decreases the baking time, while providing more uniform heat distribution and, presenting same mechanical stiffness.

2. BRIEF DESCRIPTION OF WAFER BAKING OVENS

Wafer ovens can produce several kinds of different biscuits, namely, flat wafers, hollow wafer, waffles, pancakes, ice cream cones among others. Baking ovens are designed for the industrial production of wafer in large scale, and they are composed of a front cabinet where the liquid batter is injected on the baking plates (Fig. 2). Afterwards, the batter is deposited in the baking mold, then the plates are shut tightly thus creating a pressure zone where the final product is baked to its specifications. The baking plates are supported by baking trolleys, which have rolling wheels that slide along rails (Fig. 1). The trolleys are chained to become a train. The train runs through a circuit inside the oven passing through the burning chamber where gas burners heat the plates. The wafer baking cycle takes about two minutes than the plates are open, the baked wafer sheets are removed in the starting point of the cycle and then the baking sheets are ready to receive a new product load and start a new cycle (Haas et al., 1984).

The heat is provided by the flame of the gas (NG or LPG) burners. The baking plates move across to the burner nozzles without touching them. The heat is absorbed by the fins on the back of the cooking plate and it flows by conduction through the cast iron plates to reach the baking surface at the opposite side, where the wafer batter is baked at a temperature of approximately 160°C and 180°C depending of specifications (Tiefenbacher, 2014).

3. PHYSICAL AND MATHEMATICAL MODEL

The outer side of a single plate is considered in order to capture the main features of the heating process (Fig. 2). The flames are considered to form a continuous flat plate that produces a heat flux of 20 kW m^{-2} by irradiation. The only given temperature is the baking (average phase change) temperature of the raw dough (batter) of 20°C to 180°C, read far from the plate. The oven chamber ambient temperature is assumed to be 150°C, considering the combustion gases removed by forced exhaustion.

So far, it was no possible to perform and compare simulations with experimental or real data since they are proprietary technology. Nevertheless, the simulations reached temperature level found in thermographic measurements in real operational baking plates (Fig.

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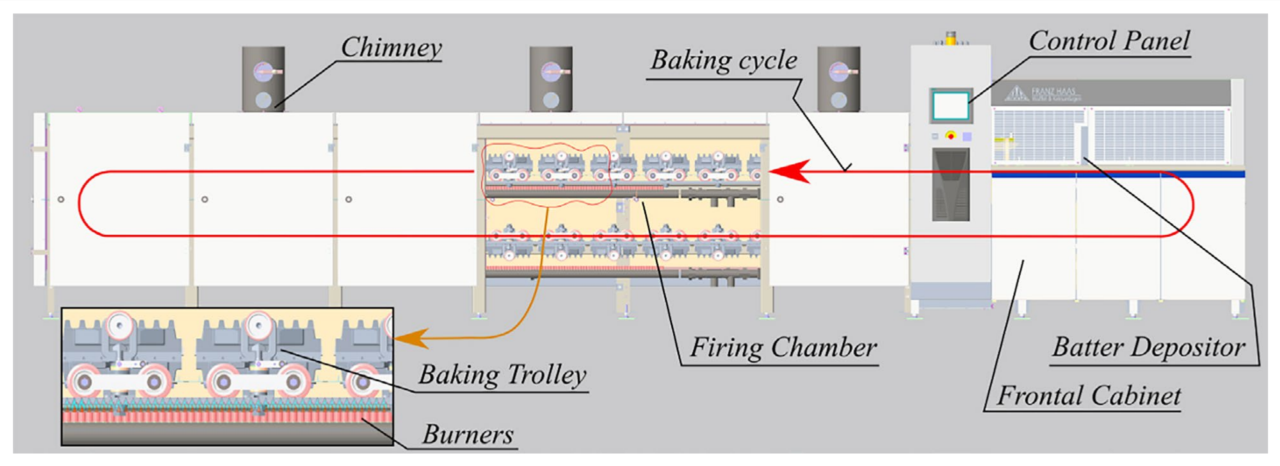

Figure 1. Schematics of an industrial flat wafer gas oven showing the baking sheets boarded on trolleys that travel along rails as a train. Burners are lined transversally to the rails. The travel cycle ends in the loading and unloading cabinet (rightmost side).

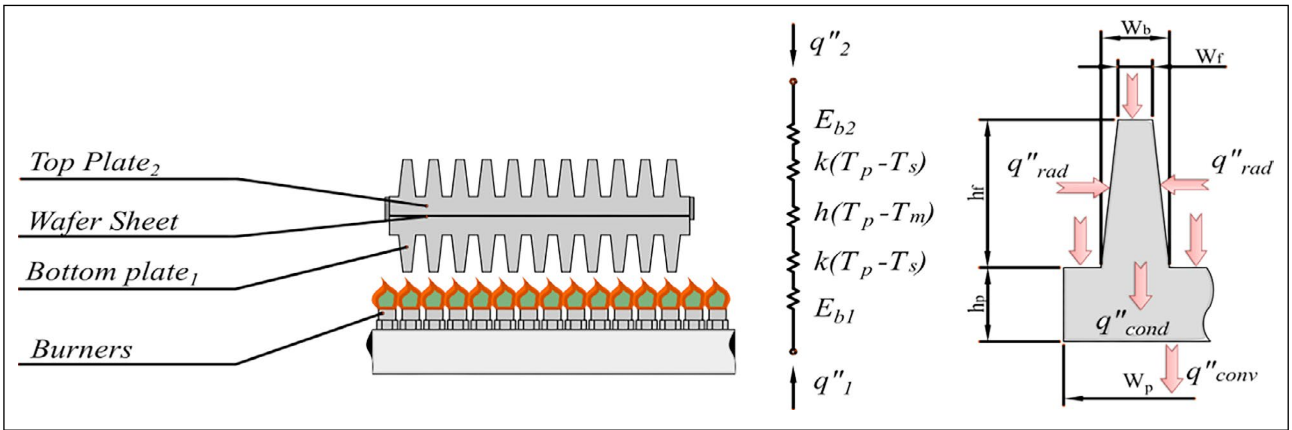

Figure 2. Schematic drawing of a baking plate with the line of burners, the heat transfer circuit analogy and a one-rectangular fin slice of the baking plate and the main dimensions.

3). That thermal photo taken during an oven test is a demonstration of the temperature level of the cooking surface in accordance with the values presented in this work. Also Karl Tiefenbacher, 2014, led an experimental laboratory and stated the requirement of wafer baking plates to work permanently in a temperature between 170°C and 200°C. Steinbach et al. (2022) also tested an oven with similar range of temperature.

The heat transfer by thermal radiation prevails. Surfaces are opaque, and the model is two dimensional. The view factor between the virtual flame and the finned surface is calculated for each point along the surface coupled with the finite element method that solves de heat conduction problem. For sake of brevity, readers are directed to classic heat transfer textbooks (e.g. Incropera, 2003 and Bejan, 2022) for the details of the thermal radiation model for every point lying along the finned surface (Fig. 2). Even though the baking process is transient, the process is considered to be in steady state at average conditions (cooking heat and temperature).

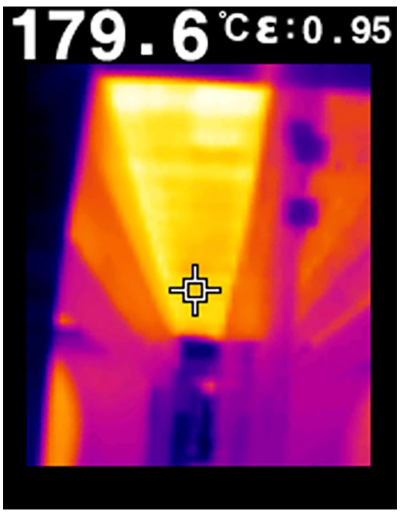

Figure 3. Thermographic images of the top baking plate during operation shows 179.6°C, the emissivity adjusted to measure with 0.95.

For the first step of the design process, the heat flux demanded by the baking process is due a highly convective regime at the batter side, namely, 100 W·m^{-2}·K this value is applied for convective heat flux in biscuit ovens (Sakin et al., 2009). The surface temperature field is coupled with 2-D, steady-state conduction in the plate with homogenous and isotropic thermal conductivity, as in Eq. (1).

$$\frac{\partial^2 T_p}{\partial x^2}+\frac{\partial^2 T_p}{\partial y^2}=0 \tag{1}$$

The temperature of the plate T_p (x,y) lies in a domain with x ranging from 0 to W_p, where W_p is the width of the base of the plate, and y ranging from 0 to h_t, where h_t is the total height of the baking plate, h_p+h_f, the height of the base baking plate plus the height of the fins.

The numerical simulations in the commercial software COMSOL® were tested for mesh independency by the observation of effect of the meshing refinement in the baking plate surface temperature profiles T_p (x). A satisfactory mesh would be one by which T_p (x) would not vary more than 1 % from the next coarser mesh, and so for average temperature and the maximum temperature difference. The mesh test starts with a coarse mesh with a free triangular topology devised automatically by the simulation software (COMSOL, 2019). Then, progressively finer meshes were tested until the acceptability conditions were met. We selected to present the meshing investigation for a baking plate with thirteen trapezoidal fins. The coarsest mesh had 368 degrees of freedom (DOFs) while the finest had 2473 nodes.

The design of the baking plate must be within some constructive dimensions necessary for project. Some degrees of freedom were defined by the Constructal Design method. The material used for baking plates was nodular cast iron (3,7C-3Si). The heating process was modeled as flat flame along the baking plates irradiating to the fins of the back of baking plates, the flames are from propane gas at a high temperature.

The oven internal ambient temperature is considered constant and uniform at 150°C. The batter is fed at the initial temperature of 20°C. The mean temperature of the flame is considered to be 1,400°C (Tiefenbacher, 2014).

The properties of the baking plate are, the heat capacity of C_{pmi}=460.55 J·kg^{-1}·K^{-1}, the mass density of 7,200 kg·m^{-3}, thermal conductivity of 52 W·m^{-1}·K^{-1} and the surface emissivity of 0.67 (Bejan, 1993).

An oven delivers around 10.5 kW per baking plate, this means an installed capacity of 60,000 W/m^2 from which part is lost. For this study, it was considered a heat transfer flux of 20,000 W/m^2 for each plate by radiation surface-to-surface, with controlled opacity.

The overall emissivity of the flame was set as 0.23 considering mainly CO_2 and O_2 as combustion products (Andersson and Johnsson, 2016).

The software computes the total radiative flux leaving a flame (radiosity). The flame condition was simplified as a solid body with a constant emissivity during an average baking time (Fig. 4). Irradiation of the flame is diffuse, as well as the baking plates surfaces. The radiation spectrum solely depends on the temperature of the baking plates (Eck et al., 2016).

In short, the mathematical formulation consists of computing the heating emitted by the burners, the heating transferred to baking plates and the heat transferred from baking plates to wafer biscuit undergoing baking. The physics is considered bi-dimensional (2-D). The remaining hypotheses are stated below:

1. Steady-state operation of the baking plates running by the oven, because of the great mass of cast iron from the baking plates;
2. Heat losses for surroundings are negligible because of thermal insulation of the oven;
3. Diffuse radiation is the predominant mechanism of heat transfer inside the oven;
4. All fluid flows throughout the oven are considered constant pressure flows;
5. The convective heat transfer coefficient is approximated as in conditions of boiling water;
6. The ambient temperature of the oven is considered stable around 150°C, by the medium temperature of the literature (Mukherjee et al., 2017).

Energy balance takes into account the heat transfer modes by conduction, convection and radiation in each surface. The energy balance at the rear surface of the baking plate is given by:

$$\dot{Q}_{cond}+\dot{Q}_{conv}+\dot{Q}_{rad}=0 \tag{2}$$

where Q_{rad} [W] is the energy transmitted from the burner by radiation, and it can be defined accounted for as shown in Eq.(3).

$$\dot{Q}_{rad}=A_s\,F_{bp}\,(J_b\text{-}J_p) \tag{3}$$

where A_s [m^2] is the rear surface area from the baking plate, F_{bp} [-] is the view factor from the burner to the baking plate. The total radiative flux leaving the burners is J_b [W/m^2] and total radiative flux leaving the rear baking surface of the plate is J_p [W/m^2] (Eq.(4)).

$$\dot{Q}_{rad}=\dot{Q}_{bp}=A_sF_{bp}\sigma\,(T_b^4\text{-}T_p^4) \tag{4}$$

where Q_{bp} [W] is the radiation net rate that leaves the burners and goes to the baking plate, σ is the Stephan-Boltzmann constant with the value 5.670373×10^{-8} W·m^{-2}·K^{-4}. T_b [K] is the flame temperature from the burner, and T_p [K] is the local temperature of the rear of the baking plate. The view factor depends of the geometry of the radiation of the burner and the baking plates, and it can be seen as the radiation from burner that is intercepted by baking plate (Eq.(5)).

$$F_{bp}=\frac{\text{radiation leaving burner } A_b \text{ and hitting the plate } A_p}{\text{total radiation leaving the burner } A_b} \quad (5)$$

In simulation software the surfaces are divided into facets in the meshing geometry, the parts were design in a CAD (computer aided design) software and imported into the simulator. The view factor is computed internally by COMSOL, using a hemicube model.

The radiant net exchange Q_{rad} [W] in which the radiation leaves the burner and arrives in the baking plate can be calculated also by the radiative interactions absorbed and reflected.

$$q_{rad}=A_s\,(J_p-G_p) \quad (6)$$

Equation (7) provides the radiosity J_p [W/m^2], where E_p [W/m^2] is the emissive power of the surface of the plate, ρ_p [-] is the baking surface reflectivity and G_p [W/m^2] is the baking plate irradiation.

$$J_p=E_p+\rho_p\,G_p \quad (7)$$

which in turn yields:

$$J_p=\varepsilon_{ff}\,E_p+(1-\varepsilon_{ff})\,G_p \quad (8)$$

where: ε_{ff} [-] is the emissivity of the cast iron set as 0.67, E_p is the power emissivity of baking plate surface, as defined by law of Stefan-Boltzmann.

$$E_p=\sigma\,(T_b^4-T_p^4) \quad (9)$$

Then the net heat transfer rate from radiation over the rear of the baking plate may be given by:

$$\dot{Q}_{rad}=\varepsilon_{ff}\frac{A_sE_p-J_p}{1-\varepsilon_{ff}} \quad (10)$$

More details of the finite element of heat conduction and other details can be found in COMSOL, 2019.

4. CONSTRUCTAL DESIGN OF THE FINNED SURFACE

The method of Constructal Design is employed in order to explore design trends of the baking plates in an industrial gas oven as described in section 2. The model consists of identifying the essential flows of a finite-size system, the constraints, the source of thermodynamic imperfections and the degrees of freedom. It is based on the Constructal Law, which was introduced in Bejan, 1997, detailed in Bejan and Lorente, 2008 and further discussed by Errera, 2018.

The numbers of degree of freedom for the fin geometry varies with the shape, namely, there are five degrees of freedom for a trapezoidal fin, four for the rectangular fin, three for the parabolic fin and two for the triangular fin when they all are straight and have the same length, *L*. The Constructal Law states that the configurations that facilitate the flow the most tend to prevail over the others. The "heat flow access" in this work is represented as the average temperature at the baking side of the plate and its non-uniformity. From limit of 2D design were simulated only the number of fins, *N*, for four different fin geometry will be shown.

The main constraint is the amount of material of the heated surface of the baking plate. For instance, for trapezoidal fins, the material volume constrained is given by Eq. (11) as detailed in Figure 2.

$$V_{cte}=\left\{N\left[\frac{(W_b+W_f)}{2}\right]h_f+h_pW_p\right\}L \quad (11)$$

where, V_{cte} [m^3] is the plate fixed volume, W_b [m] is the width of the fins base, W_f [m] is the width of the tip of the fin, h_f [m] is the height of the fin, h_p [m] is the thickness of the base of the plate, W_p [m] is the width of the base of the plate, and L [m] is the length of the plate in the third dimension not shown. In rectangular fins, $W_b=W_f$. In parabolic fins, the shape is fixed for initial simulations. The geometric parameters (Eq. (11) and Fig. 2) of each configuration (design) are determined in a non-linear algebraic solver implemented in electronic spreadsheet. W_b, W_f and h_f were determined for a fixed condition for h_p while the integer number of fins, N, varied between three and seventeen. The range of variations already took into account physical and constructive limitations.

The baking plates are supported by tongs. A locking system ensure the batter is contained between the two baking sides of the plates. When the plates are shut, a pressure chamber is formed from the steam generated from the batter itself. The high pressure load results in an elastic deformation of the baking plates, which is similar to deflection of a beam. A relation between small deformation of the plates and the better heat transfer could be achieved by calculation and graphics and then relating them to fin numbers. The deformation is calculated by the formula:

$$\delta=\frac{5\,F\,L^4}{384\,E\,J_x} \quad (12)$$

where, δ [m] is the deformation in the baking plate, *F* [N] is the force load in the baking plates due the steam pressure, E [N·m^{-2}] is the elasticity module of the cast iron, J_x [m^4] is the inertia moment of the cross section of the baking plates. The baking pressure is around 700 [kPa] (temperature of approximately 170°C), the elasticity module for cast iron was considered to be E=137×10^9 [N·m^{-2}], and the inertia moment for each configuration (shape and number of fins) was calculated in a computer aided draft software, using uniform homogenous properties.

Today, commercial baking plates are manufactured with six to eleven fins. This work explores if using more fins with different shapes could get a better heat flow transfer from the gas burners to the baking plate surface while delivering a more homogeneous temperature. The most important heat transfer mechanism is the radiation from the flame to the

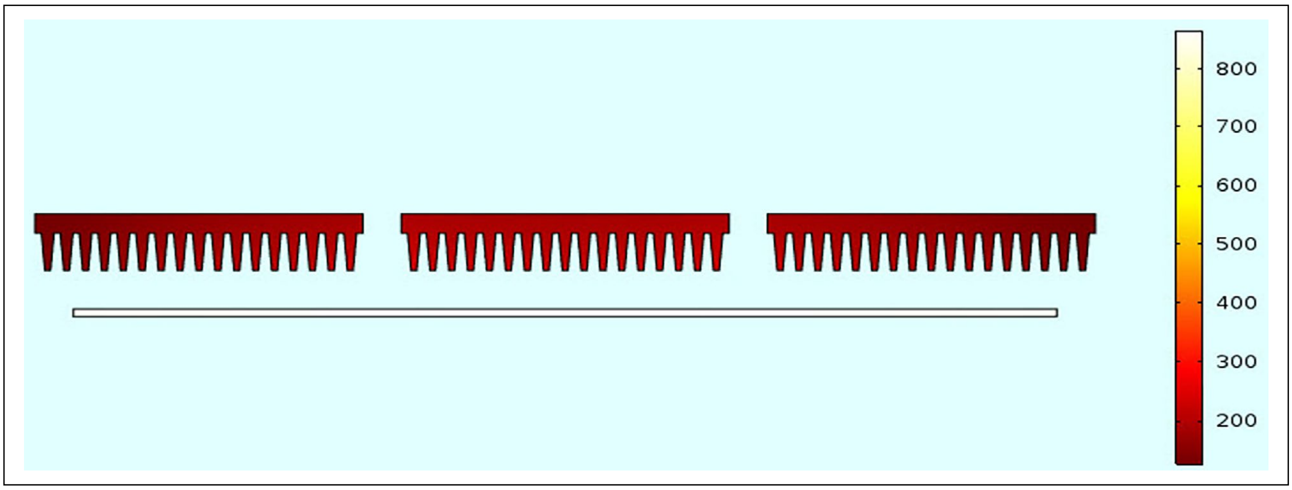

Figure 4. Illustration of the temperature field of the middle plate (the observed part of the simulation) with 17 trapezoidal fins and the flat radiant "flame".

back of the baking plates. And the view factor from the burner to the fins is higher when increase the number of the fins is increased. On the other hand, when material is added to the plate, it increases its weight and consequently it increases the production costs. The new goal is then to increase the number of fins in the plate and keep the plate weight constant, so there should be a situation where the plates has as many fins as possible, does not lose mechanical strength and transfers as much and uniformly heat as possible.

5. RESULTS AND DISCUSSION

Figure 5 and Table 1 summarize the meshing independency test. Figure 5 shows the temperature profile in the plate baking surface, $T_p(x)$, vary significantly with the mesh for the various degree of refinement supplied by the software. The temperature variation in the middle is approximately 2°C while 1.5°C in edges. The profiles oscillate with the refinement degree then converge to the "*extremely fine*" setting (COMSOL, 2019). Table 1 shows the influence of the mesh refinement setting in the average temperature of the baking surface $T_p(x)$, the corresponding maximum temperature difference, and the respective relative error. It shows acceptable relative error

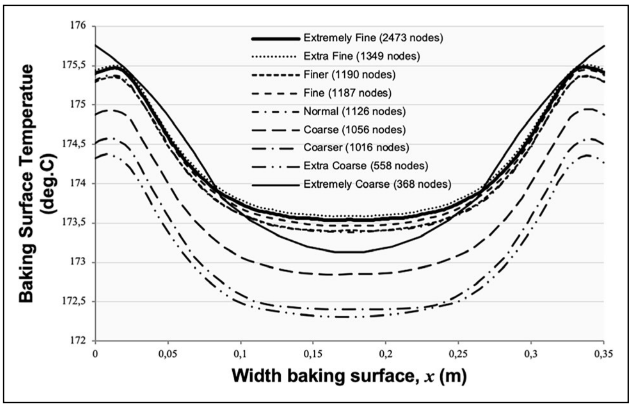

Figure 5. Temperature profile along the width of the baking surface of the plate with 13 trapezoidal fins with different mesh sizes.

beyond the "*fine*" setting with 1187 nodes. We then ultimately decided for the "*extremely fine*" setting with 2473 nodes since it seemed to capture better the variation in the edges with no significant computation time.

Initially, we compared a finned surface with a plain rectangular plate with the same volume (not shown

Table 1. Results from several predefined mesh sizes for the computational simulations of the baking plate with thirteen trapezoidal fins

Mesh refinement	Extremely fine	Extra fine	Finer	Fine	Normal	Coarse	Coarser	Extra coarse	Extremely coarse
Number of degrees of freedom, DOFs	2473	1349	1190	1187	1126	1056	1016	558	368
Number of values	239	154	109	91	82	73	64	46	28
Average T_p, °C	174.20	174.28	174.27	174.41	174.35	173.89	173.47	173.37	174.45
Relative error (%)	0.05	0.01	0.08	0.03	0.26	0.24	0.06	0.62	-
Maximum difference of T_p(x), °C	1.95	1.93	1.96	1.99	1.99	2.11	2.18	2.07	2.63
Relative error (%)	1.04	1.53	1.51	0.00	5.69	3.21	5.31	21.29	-

DOFs: Degrees of freedom

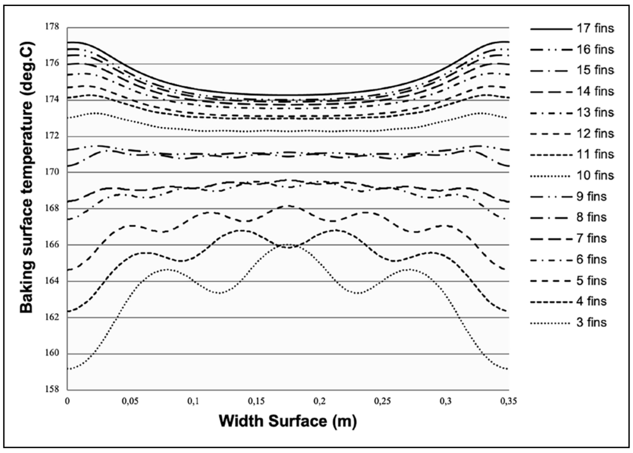

Figure 6. Temperature profile along the width of the baking surface of the plate for trapezoidal shape for different numbers of fins, *N*.

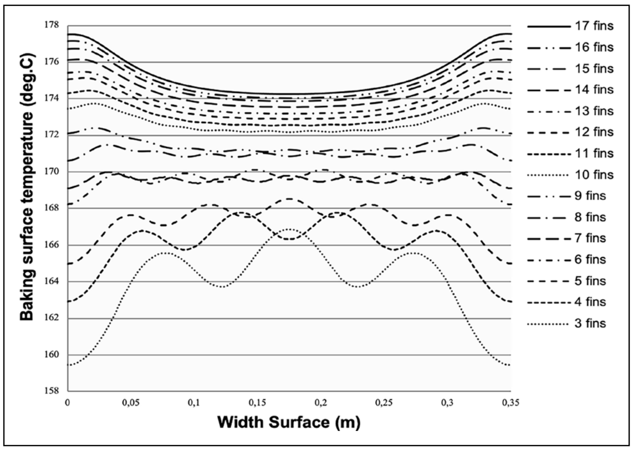

Figure 8. Temperature profile along the width of the baking surface of the plate for rectangular shape for different numbers of fins, *N*.

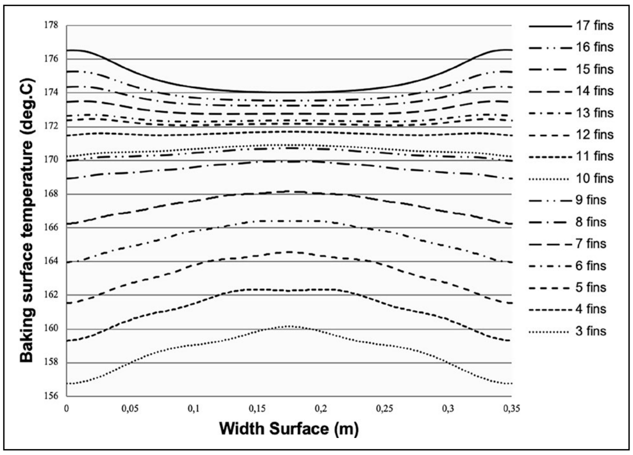

Figure 7. Temperature profile along the width of the baking surface of the plate for triangular shape for different numbers of fins, *N*.

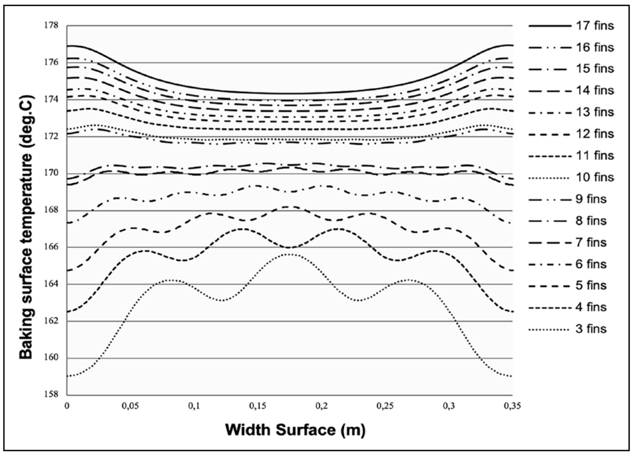

Figure 9. Temperature profile along the width of the baking surface of the plate for parabolic shape for different numbers of fins, *N*.

for conciseness). That showed indeed it is worthwhile a finned surface. In Figure 6 we show the temperature profile along the width of the baking surface of the plate for trapezoidal fins for different numbers of fins, *N*. Higher temperatures of the baking surface are reached with larger number of fins. Temperature non-uniformity seems however unavoidable since the finned surfaces are not irradiated uniformly neither the overall thermal resistance of the plate is uniform.

Figures 6 to 9 shows the baking surface temperature increasing with the number of the fins, that is, the more fins are present on the plate the higher the surface baking temperature for trapezoidal, triangular, rectangular and parabolic arrangements. The graphs show the temperature profile as a function of the position of the plate along the width of the baking surface. Fewer fins produce a wavy profile with the lower temperatures in the edges. Such wavy effect is not so visible in triangular fins (Fig. 7). For higher number of fins the temperature profile softens, the temperature in the edges become higher than the temperatures in the middle, and the differential of temperature between maximums and minimums is reduced. As the fins increases up to a number of 17, the central region of the plate has a more stable temperature, but the edges of the plate have a greater view radiation factor and end up concentrating more heat on a larger number of fins. The plates with 12 and 13 fins showed the most uniform profile, but the average temperature approximately 2 to 3°C lower than the plate with 17 fins. Those trends were present in all four fin geometries simulated.

Figure 10 shows the average surface temperature of the baking side of the plate finned with variable number of trapezoidal, parabolic, triangular and rectangular fins. The curves are ragged due to geometric approximations in solving Eq. (11) and constructive constraints. Larger number of fins facilitates the heat flow from the burners to

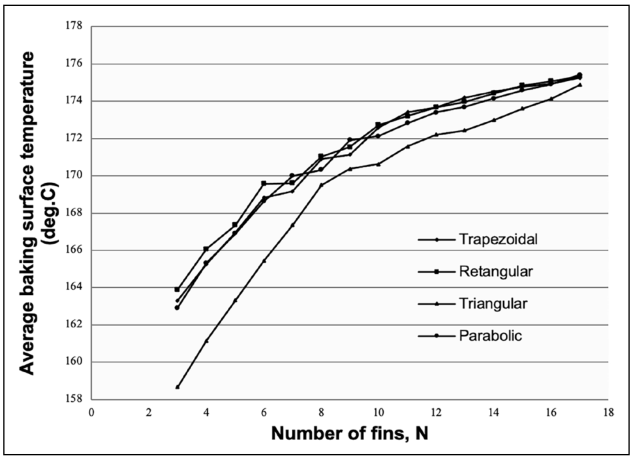

Figure 10. Average baking surface temperature of the plate finned with variable number of trapezoidal, triangular parabolic and rectangular fins.

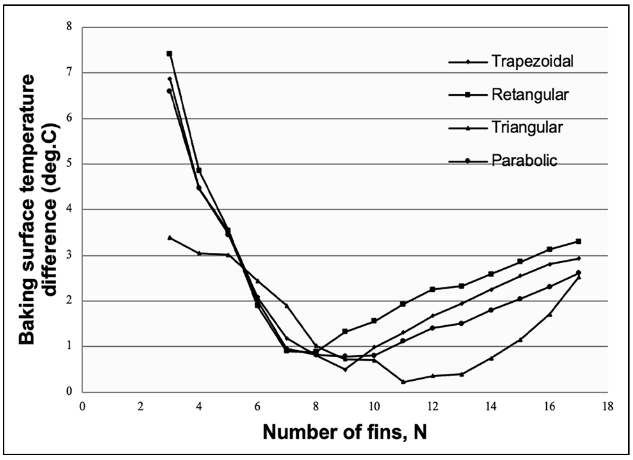

Figure 11. Difference between maximum and minimum temperature at baking surface of the plate finned with variable number of trapezoidal, triangular parabolic and rectangular fins.

the baking dough. Triangular fins deliver a lower heat flow compared to other shapes, despite the volume of the plate being the same. The view factor is affected by the reduced of polygon area.

Figure 11 shows the difference between maximum and minimum temperature for each shape and fin number, the uniformity of the temperature in the baking plate is important to reach a good baking of wafer and avoid moisture areas. The triangular shape reaches a minimum temperature difference between eleven and thirteen fins, while trapezoidal and parabolic reach the minimum between eight and ten. The minimum difference for rectangular fins is observed with eight fins. The temperature difference tends to increase as the number of fins increases past the minimum since the temperatures at the edges start to offset from the thermal plateau in the middle (Figs. 6-9)

Figure 12 shows the deformation, δ, of the plate due the baking pressure. When the inertia moment increases, the deformation decreases, the minimum deformation was found for rectangular shapes, the triangular shape have the worst performance in this case. By the practical experience a deformation larger than 250 μm would be not acceptable.

One commercial baking plate with six fins has a weight of 74 kg. Its calculated maximum deformation was of 220 μm. Its simulated average temperature of the baking surface was 163.02°C, while the difference between maximum and minimum temperature in the baking surface was found to be 3.87°C. These figures were compared with the new design proposal of baking plate of fourteen fins, which the calculated weight was of 61.2 kg. Therefore, it means there is a possible weight reduction of cast iron of 17.3 %. In both cases the maximum deformation of the plate was the same 220 μm in order to keep the same quality. The average temperature of baking surface was simulated with the same conditions and reached 174.2°C, a substantial increase of 11.2°C. Such higher baking temperature can be converted into a reduced fuel consumption for the same operating conditions. The difference between maximum and minimum temperature in the baking surface of the latter configuration was 2.26°C, a reduction of 1.61°C in comparison to the commercial baking plate. That means a better uniformity of baking surface temperature, which in practical terms, a better moisture control of the baked wafer sheet.

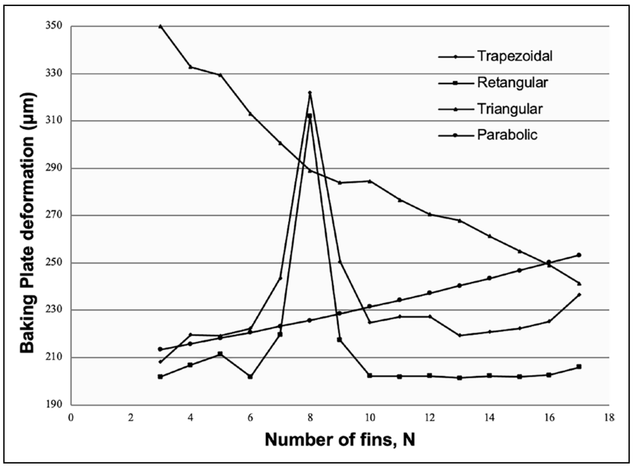

Figure 12. Maximum deformation δ of the baking plate due baking pressure caused by the steam generation from the baking dough.

The Figure 13 shows the deformation behavior of each plate with fins numbers from 3 to 17 related to the average baking surface temperature. In this graph it is possible to observe that higher temperatures are reached by the larger fin plates and the deformation of the rectangular and trapezoidal plates are within an acceptable value below 250 um except for variations due to the freedom of the Constructal Design.

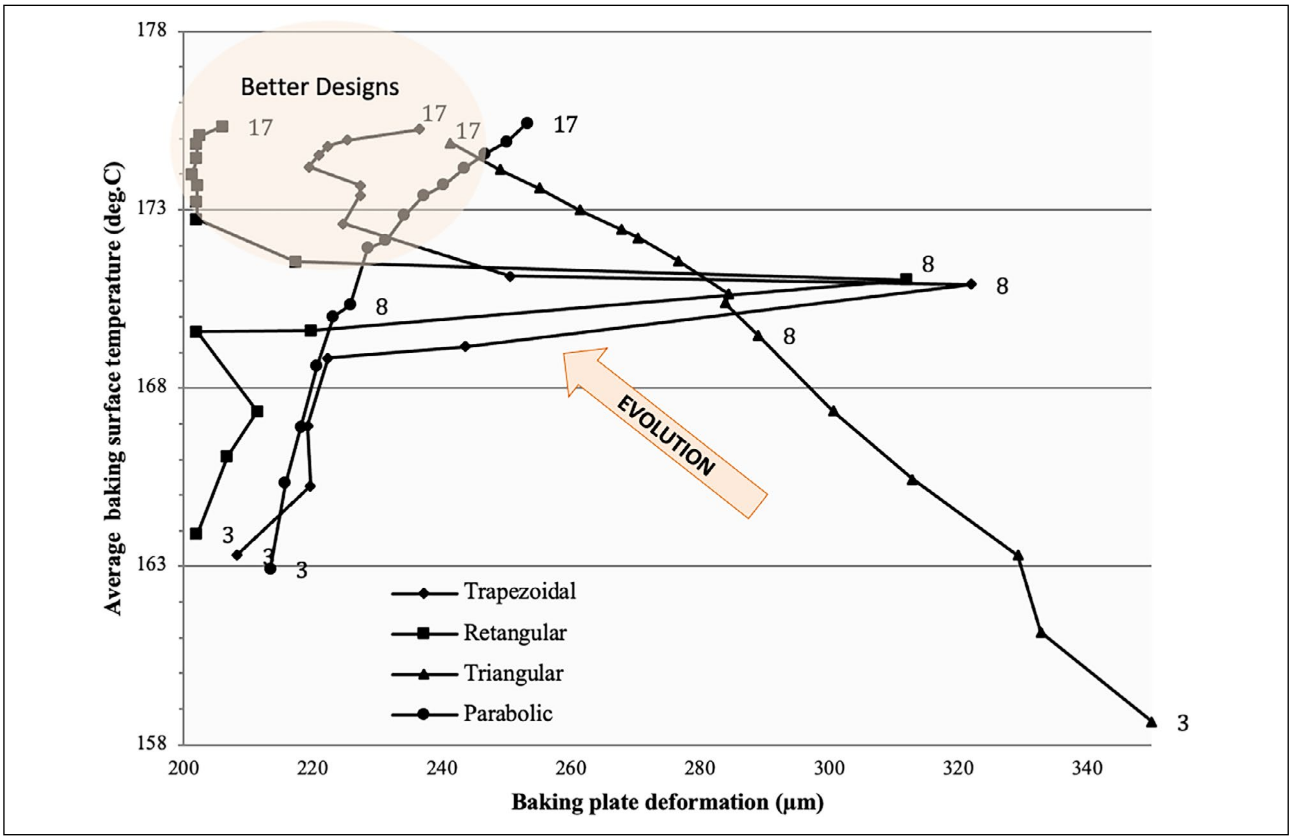

Figure 13. Overview of the trade-off between the maximum baking plate deformation versus the average baking surface temperature for all configurations tested.

6. CLOSURE

This paper explores the design possibilities of baking plates for wafer. The design of those plates must consider a trade-off of stiffness (low deformation), performance (higher temperature for a given heat flux) and temperature uniformity for quality purposes.

The physics was modeled as heat transfer by radiation from a given uniform source to a metal finned surface from which the absorbed heat is conducted to a flat surface on the opposite side of the heating source.

The method of Constructal Design was employed. The shape and the number of fins varied within steady volume constraints.

The numerical model was simple enough to sense how the main features of the design affects the project criteria set forth in the study. The results could still be verified with experimental tests based on the simulations that were teste in this work.

The method of Constructal Design provided a *landscape* of possibilities that will aid project engineers to choose the configurations that meet the goals when manufacturing, operational and economic issues will be later addressed.

In sum the new designs provide better heat transfer that in turn decreases the baking time, while it also improves heat distribution thus warranting product quality. Furthermore, the new designs provide the same mechanical resistance with less 17% material.

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DATA AVAILABILITY STATEMENT

The published publication includes all graphics

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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